SPACE TRANSFER VEHICLE CONCEPTS AND REQUIREMENTS
NAS8-37856

(NASA-CR-184491) SPACE TRANSFER VEHICLE CONCEPTS AND REQUIREMENTS. VOLUME 3: PROGRAM COST ESTIMATES (Martin Marietta Corp.) 38 p

N93-16688

Unclas

G3/16 0135347

Approved by:

W.J. Pattison

Approved by:

J.R. Hodge

NASA
Marshall Space Flight Center
Huntsville, Al. 35812

Martin Marietta
ASTRONAUTICS GROUP
Strategic Systems
P.O. Box 179
Denver, Colorado 80201

FOREWORD

This report, prepared by Martin Marietta Corporation, is submitted to George C. Marshall Space Flight Center, National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Alabama, in response to the DR-6 requirements of contract NAS8-37856, Space Transfer Vehicle Concept and Requirements. It is the DR-6 identified in Data Procurement Document No. 709.

GLOSSARY

ACC	Aft Cargo Carrier
ACS	Attitude Control System
AFE	Aeroassist Flight Experiment
Al-Li	Aluminum Lithium
ALS	Advanced Launch System
APCM	Advanced Programs Cost Model
ASE	Airborne Support Equipment
ATLO	Acceptance, Test, Launch, and Operations
ATR	Advanced Technology Roadmap
BOE	Basis of Estimate
C&DM	Configuration and Data Management
CAD	Computer-Aided Design
CDR	Critical Design Review
CER	Cost Estimating Relationship
CG	Center of Gravity
CLAAS	Closed-Loop AeroAssist Simulation
CNDB	Civil Needs Data Base
COLD-SAT	Cryogenic Onorbit Liquid Depot Storage, Acquisition, and Transfer Satellite
CSLI	Civil Space Leadership Initiatives
DDT&E	Design, Development, Test, and Evaluation
DOD	Department of Defense
DR	Data Requirement
DRM	Design Reference Missions
ETO	Earth-to-Orbit
ETR	Eastern Test Range
GEO	Geosynchronous Earth Orbit
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning Satellite
GSE	Ground Support Equipment
H/W	Hardware
I/F	Interface(s)
ILC	Initial Launch Capability
IMU	Inertial Measurement Unit
IR	Interim Review
IR&D	Independent Research and Development
IRD	Interface Requirements Document
KSC	Kennedy Space Center
L/D	Lift-to-Drag Ratio
LAD	Liquid Acquisition Devices
LCC	Life-Cycle Cost
LEO	Low-Earth Orbit

LeRC	Lewis Research Center (NASA)
LEV	Lunar Excursion Vehicle
LTV	Lunar Transfer Vehicle
LV	Launch Vehicle
MAP	Manifesting Assessment Program
MDC	McDonnell Douglas Corporation
MLI	Multilayer Insulation
MMS	Multimission Modular Spacecraft
MSFC	Marshall Space Flight Center
MSS	Manned Space Systems
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
OTV	Orbital Transfer Vehicle
P/A	Propulsion/Avionics
PDF	Probability Distribution Function
PRD	Preliminary Requirements Document
RAMP	Risk Assessment and Management Program
RCS	Reaction Control System
RFP	Request for Proposal
S/W	Software
SE	Support Equipment
SEI	Space Exploration Initiative
Sh-C	Shuttle-C
SOFI	Spray-On Foam Insulation
SSF	Space Station Freedom
STAS	Space Transportation Architecture Study
STCAEM	Space Transportation Concepts and Analysis for Exploration Missions
STIS	Space Transportation Infrastructure Study
STS	Space Transportation System
STV	Space Transfer Vehicle
STVIS	Space Transfer Vehicle Information System
TCS	Thermal Control System
TEI	Trans-Earth Injection
TMI	Trans-Mars Injection
TPS	Thermal Protection System
TT&C	Telemetry, Tracking, and Control
TVC	Thrust Vector Control
TVS	Thermodynamic Vent System
UNIS	Unified Information System
USRS	Upper Stage Responsiveness Study
VCS	Vapor Cooled Shields
WTR	Western Test Range

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The Space Transfer Vehicle (STV) Concepts and Requirements Study has been an eighteen-month study effort to develop and analyze concepts for a family of vehicles to evolve from an initial STV system into a LTS system for use with the Heavy Lift Launch Vehicle (HLLV). The study defined vehicle configurations, facility concepts, and ground and flight operations concepts. This volume reports the program cost estimates results for the this portion of the study. The STV Reference Concept described within this document provides a complete LTS system that performs both cargo and piloted Lunar missions.

Cost estimates have been developed for reference system which meets the program planning schedule, the production buys, and the launch schedule provided by the mission model. In addition, costs have been developed for providing launch capabilities from Space Station Freedom. A description of our cost estimating approach and methodology, summary cost data, cost estimates by Work Breakdown Structure (WBS) element, a funding schedule, and an economic analysis for the STV/LTS have also been included.

The current life cycle cost (LCC) estimate for the recommended concept for the initial STV (summarized in Section 3.1 and discussed in detail in Volume II) which meets the requirements stated in the Systems Requirements Document (SRD) is $10,247.3 M. This includes $624.4 M for the Design Development Test and Evaluation (DDT&E) program, $1205.2 M for the production of 22 vehicles, and $8417.7 M for launch operations for 22 missions. The average mission cost is $437.4 M.

The current LCC estimate for the recommended concept for the LTS (summarized in Section 3.2 and discussed in detail in Volume II) is $88,620.4 M. This includes $23,385.4 M for the Design Development Test and Evaluation (DDT&E) program, $6375.8 M for the production of 9 vehicles, and $58,859.2 M for launch operations for 25 missions. The average mission cost is $2610 M. Details of these estimates are discussed in Sections 2.0 and 4.0.

2.0 APPROACH, METHODOLOGY, AND RATIONALE

2.1 COST ESTIMATING METHODOLOGY

Engineering Economic Analysis (EEA) is an integral decision factor utilized in the STV system definition process. EEA decision support ensures that the cost in each of the program phases, Design, Development, Test, and Evaluation (DDT&E), Production, and Operations and Support (O&S), are all optimized to meet program goals and requirements. Figure 2.1-1 shows that the EEA approach begins early in a program. Cost avoidance studies are utilized in the requirements allocation process to assure interaction among design engineers in all disciplines so that a cost-effective system is derived. The Life Cycle Cost (LCC) of the system is estimated and then analyzed for affordability, cost containment, and cost reduction potential. The entire process is iterated until the cost in each phase is optimized.

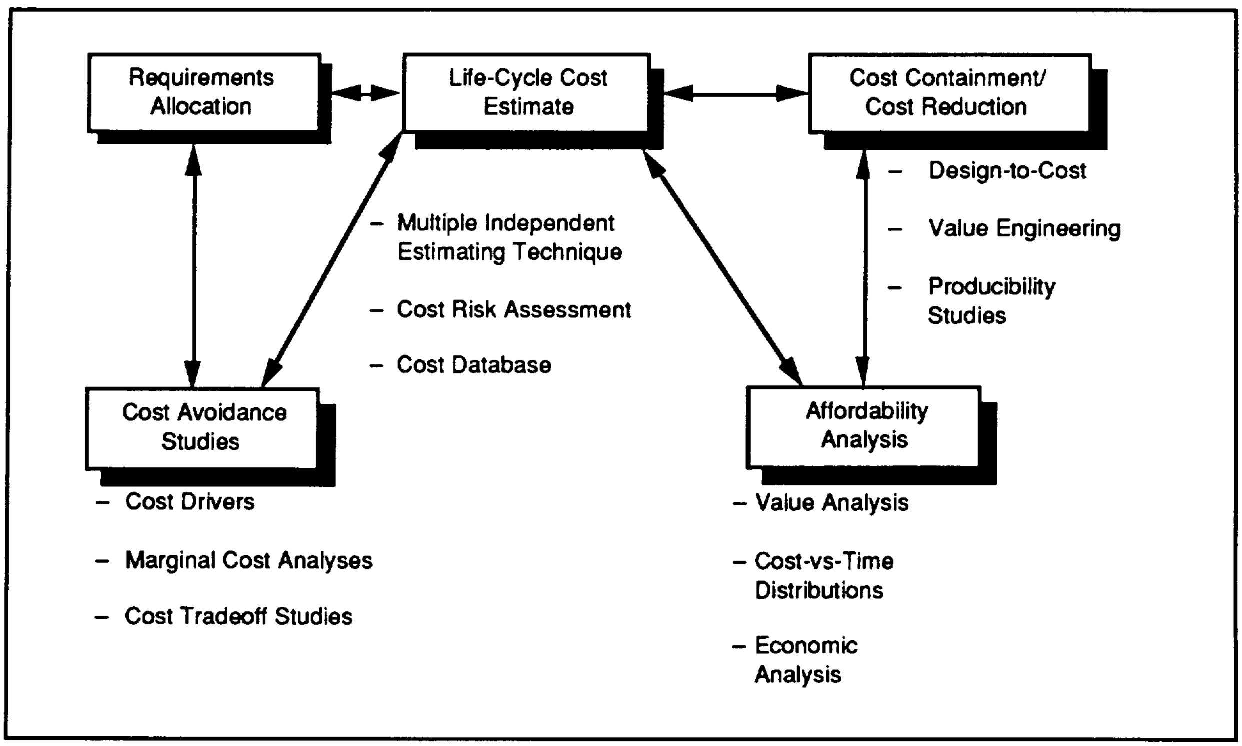


Figure 2.1-1 EEA Project Support Activities

The Martin Marietta STV cost estimating approach utilizes multiple independent estimates, as shown in Figure 2.1-2. These independent estimates are used to cross check and verify each other. The estimating techniques vary, depending on the amount and type of design or operations data available. The techniques used in this study are:

- Parametric Cost Estimating Relationships
- Historical Analogy
- Industrial Engineering Estimates
- Expert Analysis (Tops-down, Bottoms-up, or Supplier Quotes)

Parametric Cost Estimating Relationships (CERs) were derived for new systems where there was historical data from existing systems that were functionally similar. These CERs take the form of mathematical equations (as shown below) that can be derived through curve fitting techniques applied to historical cost, performance, timelines, and physical parameter data.

$$1988\ \$\ \text{in millions} = 0.135 \times WT\ (LBS)^{0.868}$$

The design parameters for the new system (weights, volumes, power requirements, etc.) were estimated and the calculations, with appropriate complexity factors, are made. Project support factors (for Systems Engineering, Program Management, etc.) were added to produce a total program cost estimate.

The historical analogy to existing design uses the historical cost data of a point design to establish the cost of a new item. This technique is normally used where design data is available on a component or at an assembly level. The estimate is accomplished by relating the two designs in terms of technical characteristics and by making a judgement as to the degree of similarity.

Industrial Engineering estimates are production costs built up in terms of material usage and labor operations. Individual piece parts are analyzed to determine the quantity and type of material needed; and the specific operations, such as cutting, grinding, welding, cleaning, and inspection, are identified along with the manpower for conducting each operation. Standard labor, overhead, and General and Administrative rates are then applied to determine the cost. Such an estimate requires a great amount of detail and is therefore more suited to a more firm type of estimate.

The Tops-down expert analysis is often the only means of estimating available, especially if back up data is scarce or nonexistent. This process involves estimates made by the engineers that are the most familiar with the system. A thorough understanding of the rationale involved in the estimate, as well as any assumptions made, are documented and evaluated.

The Bottoms-up expert analysis is the most complete type of cost estimate and involves the most detail. The estimate takes a detailed listing of the tasks to be performed and applies the manpower, labor skill mix, computer units, number of trips, tooling materials, supplies, etc. to them. Specific labor, overhead, and General and Administrative rates are then applied to give a complete estimate.

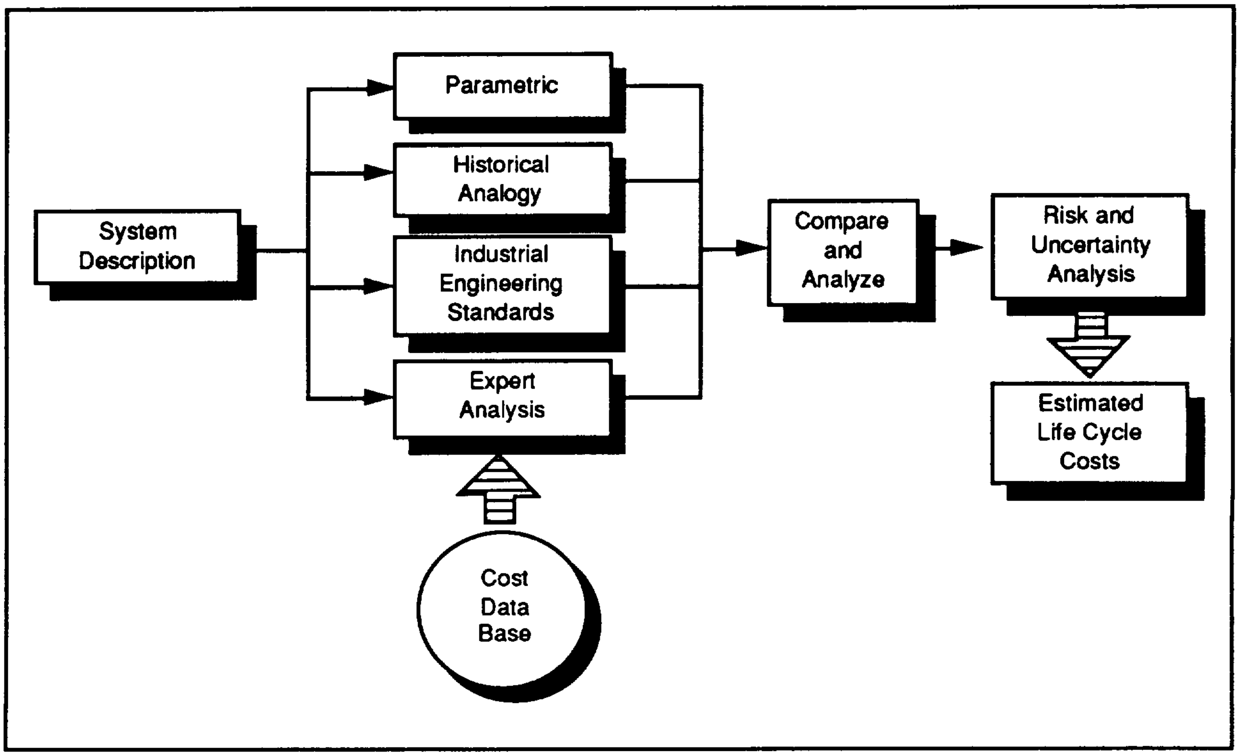


Figure 2.1-2 Multiple Independent Estimate Method of Life Cycle Cost

Supplier quotes are obtained by soliciting experienced suppliers to estimate the cost of an item using specifications of performance and design requirements and definitions of production quantities, rates, and schedules. Wraparound factors are applied to these quotes to include the internal effort to checkout, package, assemble, and ship the hardware.

In the early phases of this STV program, no single estimating technique can be used to cover all aspects of a program cost. Table 2.1-1 lists the primary estimating techniques that were used in developing the STV estimate. For the most part, the costs were based on data contained in a proprietary Martin Marietta database. Also listed in Table 2.1-1 are the techniques that were used to check the reasonableness of the costs. These techniques were used for the work breakdown structure (WBS) elements that historically drive cost such as avionics, software, and operations and they would be used for all elements in the detailed estimates that Martin Marietta prepares for actual hardware development and production.

We have used our vehicle definitions, preliminary development plans and schedules, and the developed WBS (including MSFC inputs) to prepare system cost estimates. All phases of the LCC of the system have been addressed, including DDT&E, facilities, production, and operations costs. We have used our PC-based Advanced Programs Cost Model (APCM) as the tool to develop our estimates. APCM has been used for cost analysis on Phase A programs such as STAS, USRS,

Table 2.1-1 STV Costing Methodology

WBS Element	Basis of Estimate	Comparative Method
Vehicle	Historical $/lb, Vendor Quotes	Analogy, Engineering Estimate
Software	Bottoms-Up, Engr Estimate	Engineering Estimate
Support Equipment	Analogy, Historical Factor	Engineering Estimate
Tooling	Historical Factor, Complexity	Engineering Estimate
System Test	Historical Factor, Complexity	Analogy, Engineering Estimate
Facilities	$/Sq Ft, Engineering Estimate	Analogy
Operations	Bottoms-Up, Engr Estimate	Engineering Estimate
Systems Engineering	Historical Factor	Engineering Estimate
Program Management	Historical Factor	Engineering Estimate
ETO Costs	$/lb to LEO	Engineering Estimate
LEO Node	Engineering Estimate	Analogy
Growth and Fee	NASA Supplied Factors	N/A

and ALS. It uses historical data from such flight hardware programs as Titan, External Tank, Shuttle, Peacekeeper, Small ICBM, Transtage, and the candidate MLV-II stage to develop cost estimating relationships (CER) based on system parameters. As shown in Figure 2.1-3, the design aspects of the vehicle system elements were used to determine the design and development and first unit costs. Projected flight rates were used to determine the production rates and the number of processing facilities required to maintain the launch schedule. Synergism and commonality between the vehicle elements were accounted for in the production and operations costs by taking advantage of learning and rate efficiencies for larger quantities. Facility costs have been estimated based on size and processing capability. Manpower and work shifts have been varied to simulate a true launch processing environment.

Using the estimates developed by the APCM, STV analyses concentrated on defining the cost driving requirements. Understanding the difference between a high-cost area and a cost driver is critical. Knowing only the high cost areas aids little in reducing costs. The engineers must also know which requirements are influencing the cost so that the design will avoid the costly requirements.

In order to understand which requirements are influencing cost, sensitivity analyses are conducted on various requirements, such as responsiveness. Sensitivity analyses serve to define the magnitude a variation makes on the cost. If cost is highly sensitive to a requirement, the requirement is termed a cost driver. Sensitivity analyses often will define a "knee" in the cost curve below which a change in the requirement does not affect cost greatly.

The results of the cost driver and sensitivity analyses, along with the cost and schedule risk have been used to identify cost uncertainties and estimate their range of uncertainty. They have been applied to specific system and subsystem trades to ensure that the cost-effective alternatives were identified.

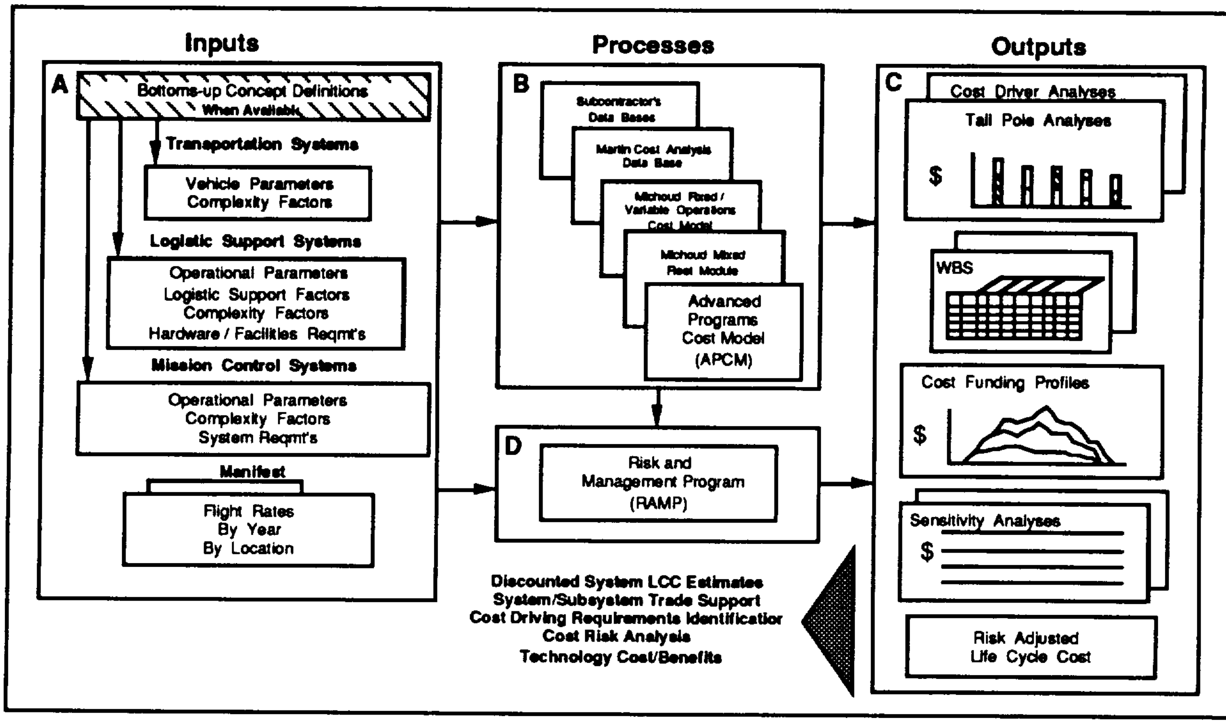


Figure 2.1-3 STV Cost Analysis Methodology

2.2 GROUNDRULES AND ASSUMPTIONS

Groundrules and assumptions were established so all cost estimates could be developed with a common basis. This section documents these in subsections for the general groundrules and assumptions provided by the government (Section. 2.2.1), the additional assumptions Martin Marietta found necessary as analysis proceeded (Section 2.2.2), and the groundrules and assumptions for the program phases of non-recurring, production, and integration and operations (Sections. 2.2.3, 2.2.4, and 2.2.5 respectively).

2.2.1 Government Furnished Groundrules and Assumptions (MSFC)

1) All cost estimates will be reported in millions of constant FY91 dollars. Only Office of Secretary of Defence (OSD) inflation indices shall be used to develop an FY91 cost base.

2) A 15% weight contingency will be included for cost estimates derived from weight based cost estimating relationships (CER).

3) A 35% allowance will be used to account for growth and changes in the program requirements

4) An 8% allowance will be used for prime contractor fee.

5) A 15% allowance will be used to account for government support beyond the scope of the prime contract.

6) A 0.5% allowance will be used to account for Defense Contractor Administration Service (DCAS) taxes.

7) No separate management reserve or risk cost is to be identified as a separate cost element. All cost risks and uncertainties are to be reflected in appropriate WBS costs.

8) Major cost risks and cost uncertainties are to be identified separately along with the rationale explaining what costs are included or excluded from the WBS baseline.

9) Any additional groundrules and/or assumptions used by the contractor should be explicitly stated.

10) Any deviations from the above groundrules and assumptions should be explicitly stated.

2.2.2 Overall Program Groundrules and Assumptions

These assumptions are in addition to the government groundrules and assumptions presented in Section 2.2.1. The following groundrules and assumptions were used in preparing the cost estimates for the STV Program. They apply regardless of program phase, WBS element, or subsystem allocation.

1) The cost estimates include overhead and general and administrative (G&A) costs.

2) The cost estimates include contractor costs only. No major government support has been included.

3) The schedule used in preparing the cost estimates for the STV included the DDT&E phase from October 1995 to April 2001 (67 months), the production buy of 22 units beginning in April 2000, and vehicle processing at KSC beginning in October 2000.

4) The schedule used in preparing the cost estimates for the LTS included the DDT&E phase from October 1997 to April 2004 (79 months), the production buy of 9 units plus recurring hardware beginning in April 2002, and vehicle processing at KSC beginning in October 2003.

2.2.3 Non-recurring Groundrules and Assumptions

1) The STV design is based on information generated during Phase I of the STV Concepts and Requirements Study effort, and documented in detail in Volume II of the STV Final Report, MCR-91-7503, March, 1991.

2) Baseline costs are provided for the scenario requiring four Lunar expendable cargo launches and 21 piloted missions over 25 years for the LTS based on the Option 5 requirements, dated December 1989, and the PSS Reference Architecture Document 90-2, dated May 1990.

3) The non-recurring costs associated with the STV/LTS consist of the Design, Development, Test, and Evaluation (DDT&E) costs.

4) No flight hardware is included in the non-recurring costs. The hardware included is that hardware built for developmental and qualification test purposes only.

5) System Test and Evaluation costs include the qualification test vehicle hardware and the thermal vacuum, acoustics, and vibration tests as well a flight operations for those vehicles.

6) Developmental and testing spares costs are included in each subsystem cost.

7) No direct Independent Validation and Verification (IV&V) effort is included, but the contractor support effort is included.

8) The cost of real estate and environmental impact assessments are not included.

9) Main engine development costs include the work for development and qualification of the Advanced Space Engine (ASE)..

10) STV Initial Launch Capability (ILC) occurs in 2000 with LTS ILC occurs in 2002.

11) STV Initial Operating Capability (IOC) occurs in 2001 with LTS IOC occurs in 2004.

12) STV/LTS Operational phase is 25 years in duration.

2.2.4 Production Groundrules and Assumptions

1) Production consists of the recurring costs associated with the fabrication and assembly of the STV/LTS flight vehicles.

2) The first STV build will be completed in 2000.

3) Sustaining engineering and program management costs are included.

4) Manufacturing and Qualification spares are included in the vehicle production costs.

2.2.5 Operations Groundrules and Assumptions

1) STV/LTS launches will be supported by a Martin Marietta team.

2) Operations costs are for STV/LTS processing, payload integration, LEO node operations, flight operations, spares, and ETO.

3) Space Station IVA costs are assumed to be $150K per hour.

4) Space Station EVA costs are assumed to be $300K per hour.

5) ETO costs are assumed to be $2500 per pound delivered.

2.3 WORK BREAKDOWN STRUCTURE AND DICTIONARY

The Work Breakdown Structure and Dictionary were used as a baseline to define the elements of the STV/LTS program. This WBS was used as a guideline in developing the STV/LTS cost estimates discussed in this volume. The details of the WBS and WBS Dictionary are contained in DR-5, MCR-91-7505.

3.0 RECOMMENDED CONCEPT TECHNICAL DESCRIPTIONS

The STV family of vehicles that came out of the Concept Selection Trade Study analysis shows that the Lunar missions impose the most stringent requirements on the STV. The design approach taken has been to develop a vehicle that meets these design requirements and then evaluates the design to identify the elements that best satisfy the mission requirements for an initial Ground Based STV, a later Space Basing of the STV, and finally the Mars mission profile.

3.1 INITIAL STV CONCEPT

A common set of engines, tanksets, cores, aerobrakes, crew modules, subsystems, etc. were found to be applicable in the development of various ground- or space-based, expendable or reusable STV configurations including the Lunar transportation system.

The ability of the baseline vehicle or elements of the baseline vehicle to perform the other DRM cargo requirements was evaluated and is depicted in Table 3.1-1. All DRM cargo requirements can

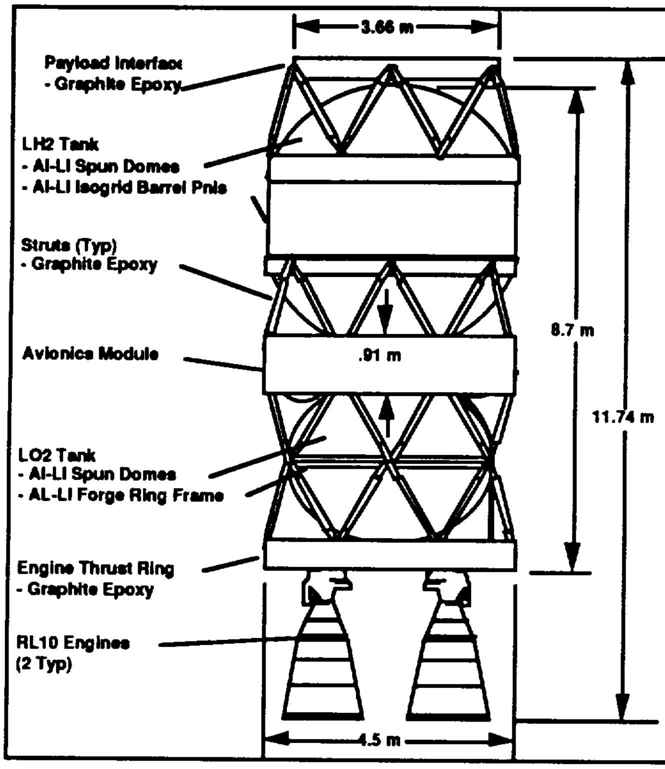
Table 3.1-1 Baseline Vehicle Adaptability

DRM	Description	Cargo Requirement	LTS/STV Configuration
E - 1	Manned GEO Servicing	4.0 t delivery & return	4E-5B Core w/AB, Crew Module, & 43 t Prop in Drop Tanks
E - 2	10 t GEO Platform Delivery (DELETED IN CNDB '90)	10.0 t delivery	Interim Vehicle (12.9 t maximum capability)
E - 3	6.4 t GEO Payload Delivery (DoD)	6.4 t delivery	Interim Vehicle (12.9 t maximum capability)
E - 4	Unmanned Polar Platform Servicing	3.5 t delivery & return	4E-5B Core w/AB, & 26.3 t Prop in Drop Tanks
P - 1	Comet Nucleus Sample Return (DELETED IN CNDB '90)	16.0 t delivery	4E-5B Core & 5.1 t Prop in Drop Tanks

DRM Propellant Loads Are Based on the Use of RL10A-4 Engines (449.5 sec)

be met by either the initial STV or the baseline core vehicle with only one set of drop tanks. The capability of the stages was determined using the RL10A-4 cryogenic engine at 449.5 seconds of Isp and the various pieces of the LTS as listed in the table. The table shows the minimum needs of the core vehicle to meet the DRM cargo requirements in terms of extra propellant and subsystems, e.g. the crew module for the manned mission.

The initial STV, shown in Figure 3.1-1 is a ground-based expendable version and can be built from the common set of elements and subsystems. A common tankset and two engines with limited subsystems form the basis for this vehicle. It is sized to fit within a 4.6 m (15 ft) diameter payload shroud for delivery to orbit. The dry weight of the vehicle is about 3 t with a length of nearly 12 m. With approximately 28 tonnes of LOX/LH_2 propellant in the tankset, the vehicle can deliver 12.9 tonnes of payload to a geosynchronous orbit.



Mass Properties	
Components	**Mass (t)**
Structure	0.68
Propellant Tanks	0.52
Propulsion System	0.31
Main Engines	0.31
RCS ystem	0.09
GN&C	0.07
Communication & Data Handling	0.15
Electrical Power	0.25
Thermal Control System	0.38
Contingency (15%)	0.41
Total Dry Weight	3.17

Performance ~ 12.9 t Max to GEO

Figure 3.1-1 Ground-Based Expendable Version

3.2 LTS CONCEPT

The STV concept definition for a vehicle that is configured for the Lunar mission is based on the requirements set out in the STV Statement of Work (SOW), with additional derived requirements from the Option 5 Planetary Surface System (PSS) documents, and the system trade studies and analyses. These studies and analyses recommend that the orbital mechanics designated as Lunar Architecture #1 (LA#1) is the best at meeting these requirements. Briefly stated LA#1 uses a LEO node as the start and finish of the Lunar mission for both crew and cargo flights. The LEO node is used for assembly, checkout, and refurbishment of the Lunar STV concept. Additional elements of the orbital mechanics require the vehicle orbit in Low Lunar Orbit (LLO) before lunar descent, have a lunar trajectory that encompasses a free earth return for an abort scenario, and returns to the LEO node via an aerobraking pass through the atmosphere.

Once the Lunar mission profile shown in Figure 3.2-1, was selected, the following key design drivers were integrated into the development and definition of vehicle configuration candidates:

a) The system shall deliver 14.6 tonnes of cargo and 4 crew to Lunar surface and return
b) The system shall deliver 33.0 tonnes of cargo on unmanned flight to the Lunar surface
c) LEO transportation node shall be Space Station Freedom (SSF)
d) The propulsion system shall utilize cryogenic propellant
e) The system shall be reusable for a minimum of five missions

These design drivers were also filtered through the subsystems trade study analysis and finally incorporated into the vehicle design.

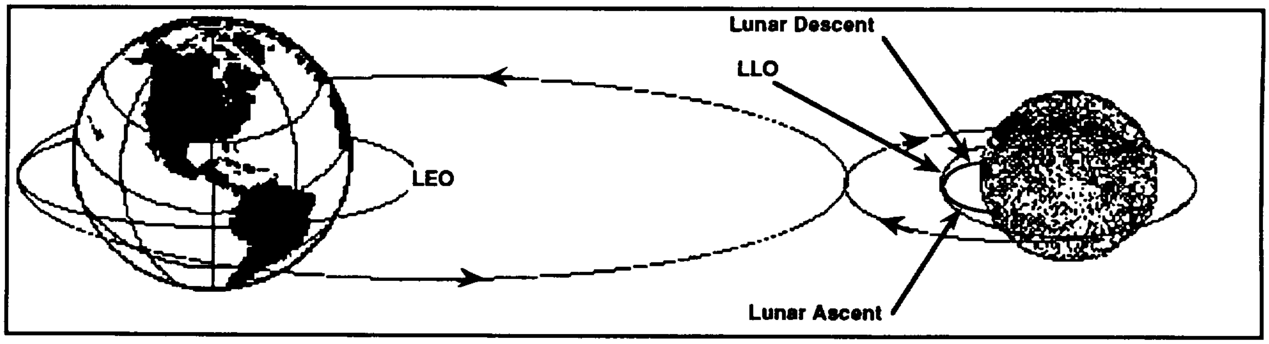


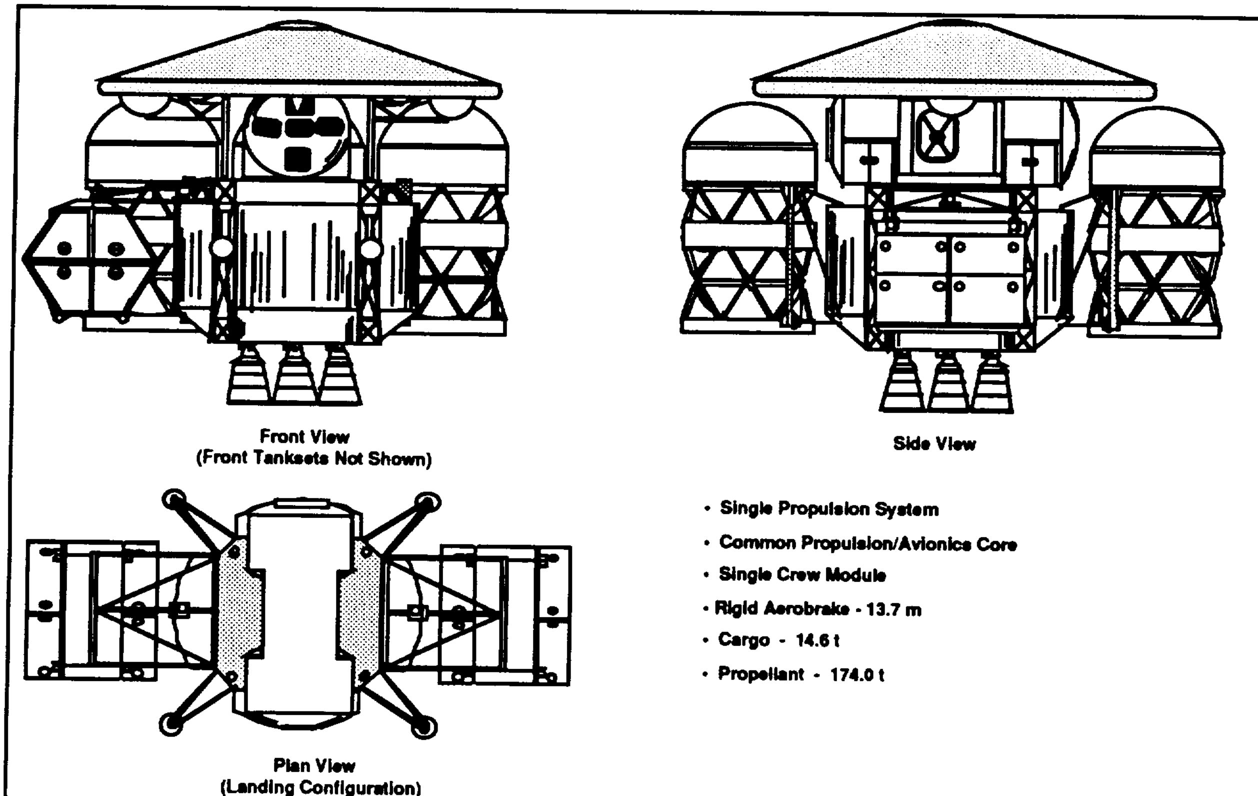
Figure 3.2-1 Lunar Mission Profile

3.2.1 LTS VEHICLE

The STV consists of a family of vehicles which share common elements performing both cargo and piloted/cargo missions such as GEO delivery, lunar, and planetary (Mars mission). That portion of the STV family that deals with the lunar missions is called the Lunar STV or the Lunar Transportation System (LTS). The LTS is comprised of two mission profiles: (1) the Cargo mission capable of delivering 33 tonnes to the lunar surface and (2) the Piloted/cargo mission capable of delivering a crew of 4 plus 14.6 tonnes to the lunar surface. These mission profiles reflect the flights and cargo manifesting schedules developed from the Option 5 Lunar Exploration Requirements Levels I - III.

A derived requirement was developed from the studies that the final cargo and piloted vehicles would share common elements, producing a family of vehicles that have common structural core, propulsion and avionics equipment, drop tanks, and can be configured for either type of mission with no major modification to these elements. The detail definition of each vehicle configuration, performance, mass properties, structure, subsystem, cargo and crew handling, and operations will be discussed in the following section. The evolutionary aspects of the configuration to perform the initial STV mission and the planetary mission are detailed at the end of this section.

3.2.1.1 Piloted Concept Overview—The LTS piloted configuration for the single propulsion system concept is shown in Figure 3.2.1.1-1. A crew module, six drop tanksets, and an aerobrake with its associated equipment are added to the propulsion/avionics core. The piloted vehicle dry mass is 27.58 tonnes. The configuration can deliver 15.26 tonnes of cargo (14.6 tonnes cargo plus cargo supports) in addition to the crew of 4 to the Lunar surface and return the vehicle and crew to LEO using approximately 174 tonnes of LOX/LH_2 propellant. TEI and LOI propellant is housed in the drop tank sets, ascent and descent propellant is found in the core, and the return propellant is housed in two sets of tanks within the aerobrake. The 13.72 m rigid aerobrake has been designed to protect the crew during the aeroassisted maneuver before returning to Space Station Freedom.



- Single Propulsion System
- Common Propulsion/Avionics Core
- Single Crew Module
- Rigid Aerobrake - 13.7 m
- Cargo - 14.6 t
- Propellant - 174.0 t

Figure 3.2.1.1-1 Piloted LTS Configuration

3.2.1.2 Cargo Concept Overview—The LTS cargo expendable configuration for the single propulsion system concept is shown in Figure 3.2.1.2-1. To form the cargo expendable configuration, a cargo platform (10.5 m x 14.8 m) and six drop tanksets have been added to the propulsion/avionics core. The cargo vehicle dry mass is 18.75 tonnes and can deliver 33 tonnes of cargo to the Lunar surface using 146.5 tonnes of LOX/LH_2 propellant loaded into the drop tanks and core tanks. The Flight 1 cargo manifest shown in the plan view is a typical arrangement for the four cargo missions.

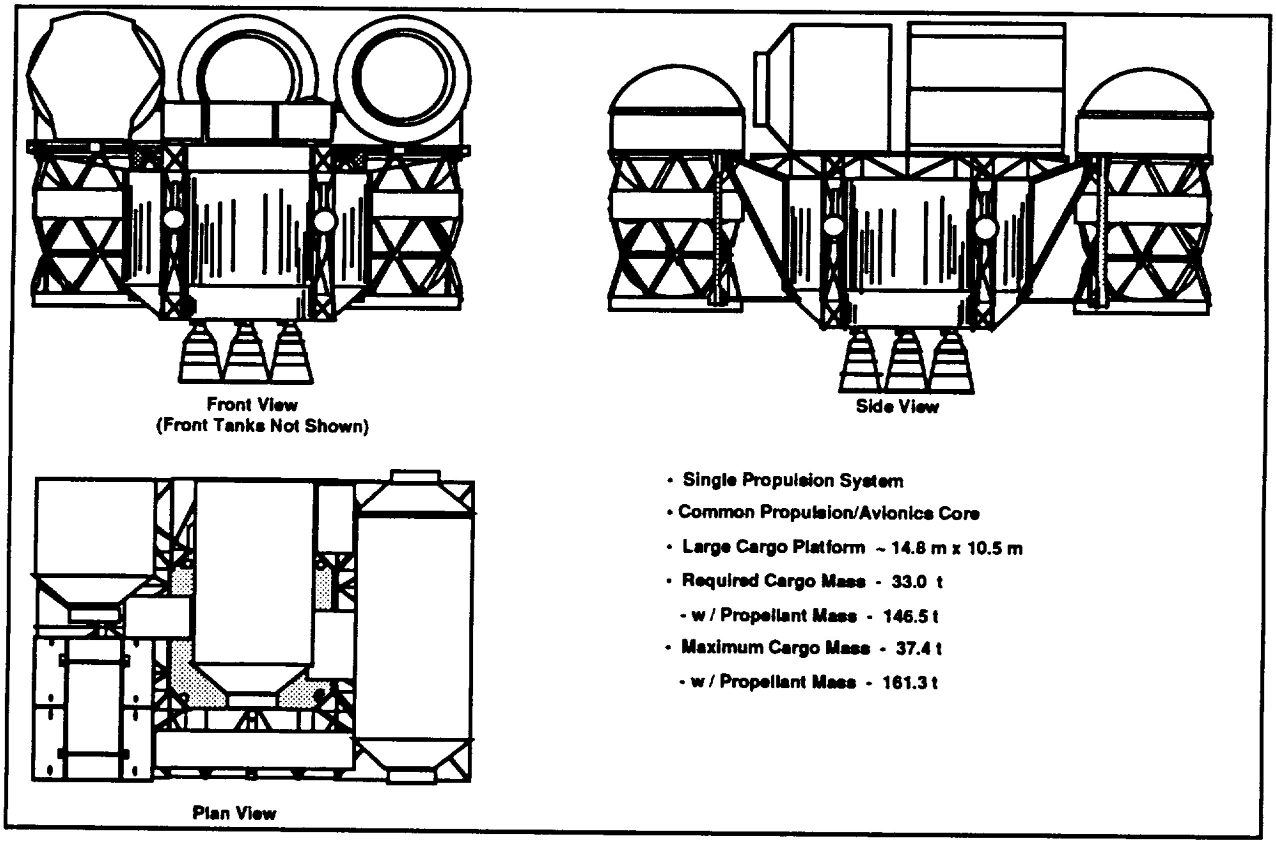


Figure 3.2.1.2-1 Cargo LTS Configuration

3.3 LAUNCH PROCESSING

Based on the above defined LTS configuration, the LTS operations concept that will be addressed in this section identifies the ground processing requirements to prepare elements for launch to LEO, the Earth-To-Orbit (ETO) transportation of the configuration elements, assembly & checkout of the system at LEO, flight operations from LEO to LLO, decent and ascent and LLO rendezvous and docking, flight operations from LLO to LEO, and post flight checkout and refurbishment of the system. Figure 3.3-1 shows an overview of the elements required to perform the lunar mission. Other elements of this concept that currently have not be defined include, direct injection (ground based) systems and GEO and polar flight operations.

This scenario is designed to support the current "Option 5" mission as defined in the Space Exploration Initiative plan an supplement in the STV DRM requirements. Volume II of this report provides the manifesting plan to support both the Lunar and near Earth missions, which is the baseline for the details defined by the STV operations scenario.

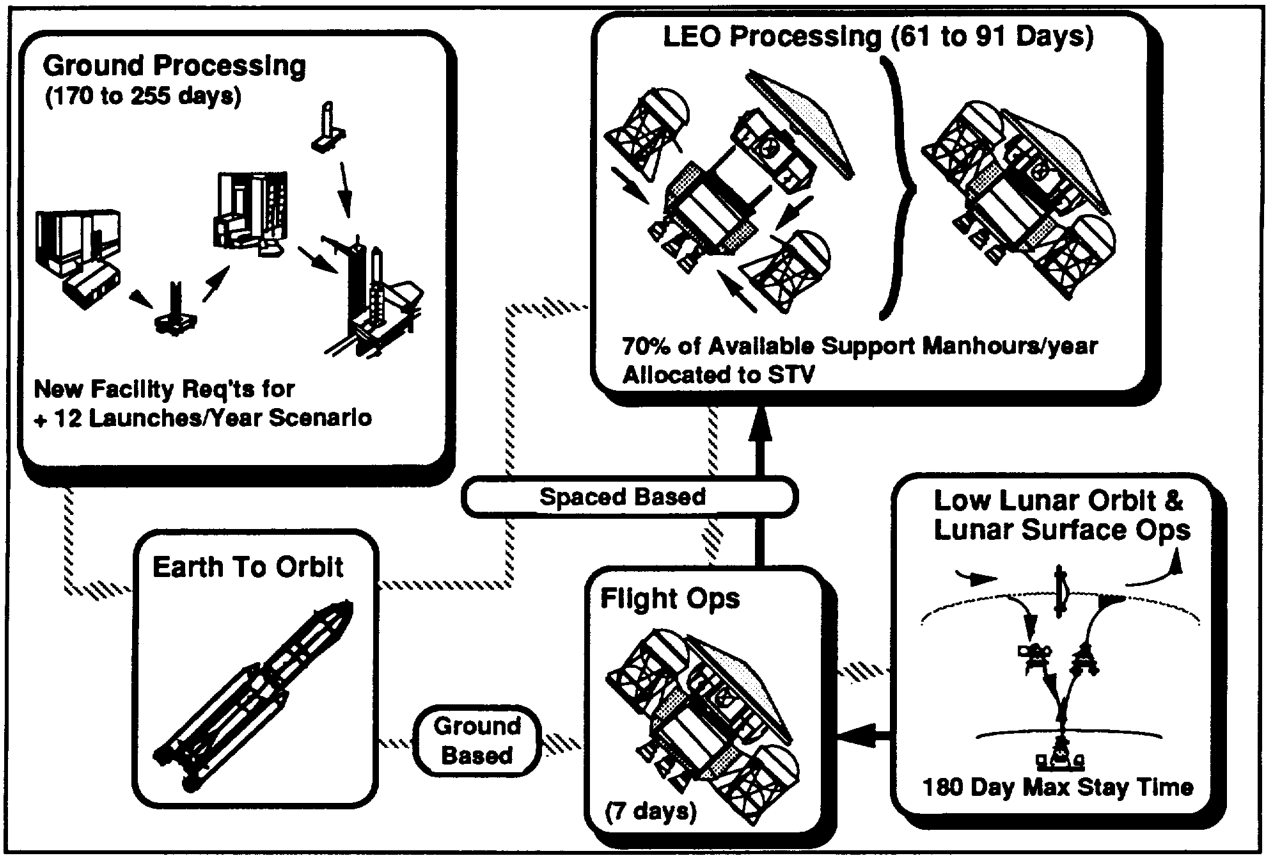


Figure 3.3-1 STV Operations Scenario

4.0 SUMMARY COST PRESENTATION

4.1 TOP LEVEL COST SUMMARY

Table 4.1-1 shows the STV top level cost by program phase and by major WBS element. It includes the production and launch of 22 vehicles with a LCC of $9809.9 M. The DDT&E cost is $624.4 M, the production cost is $1205.4 M ($55 M average unit cost), and the Operations cost is $8417.7.M.

Table 4.1-1 also shows the overall cost for the LTS program, including the production of 9 vehicles and launch of 25 missions, is $88,620.4 M. The DDT&E cost is $23,385.4 M, the production cost is $6,375.8 M ($708 M average unit cost), and the Integration and Operations cost is $58,859.2 M.

Table 4.1-1 Top Level Cost Summary

Element	DDT&E	Prod	Ops	LCC
Space Transfer Vehicle	451.8	871.9	6090.0	7413.7
Growth and Fee	172.6	333.3	2327.7	2833.6
TOTAL	624.4	1205.2	8417.7	10,247.3
Lunar Transportation System	16,918.7	4612.7	42,583.1	64,114.5
Growth and Fee	6466.7	1763.1	16,276.1	24,505.9
TOTAL	23,385.4	6375.8	58,859.2	88,620.4
STV/LTS TOTAL	24,009.8	7581.0	67,276.9	98,867.7

Costs Reported in Millions of 1991 Dollars

4.2 COST BY WBS

Table 4.2-1 shows the STV LCC breakout by major WBS element. The total DDT&E cost for the LTS program is projected to be $624.4 M. The total Production cost for the STV program is projected to be $1205.2 M. The total Operations cost for the STV program is projected to be $8417.7 M.

Table 4.2-2 shows the LTS LCC breakout by major WBS element. The total DDT&E cost for the LTS program is projected to be $23,385.4 M. The total Production cost for the LTS program is projected to be $6,375.8 M. The total Operations cost for the LTS program is projected to be $58,859.2 M.

Table 4.2-1 STV Cost by WBS Element

Element	DDT&E	Prod	Ops	LCC
Vehicle	117.8	689.2	0.0	807.0
Software	50.0	0.0	0.0	50.0
Support Equipment	17.7	0.0	0.0	17.7
System Test	67.1	0.0	0.0	67.1
Facilities	50.0	0.0	0.0	50.0
Operations	13.0	0.0	466.4	479.4
Systems Engineering	95.1	103.4	70.0	268.5
Program Management	41.1	79.3	53.6	174.0
Sub Total	451.8	871.9	590.0	1913.7
ETO Costs	0.0	0.0	5500.0	5500.0
Growth and Fee	172.6	333.3	2327.7	2833.6
TOTAL	624.4	1205.2	8417.7	10,247.3

Costs Reported in Millions of 1991 Dollars

Table 4.2-2 LTS Cost by WBS Element

Element	DDT&E	Prod	Ops	LCC
Core Stage/Lander (w/ Crew Cab)	2038.9	2538.7	0.0	4577.6
TLI Tanks	68.8	646.6	0.0	715.4
LOI Tanks	60.8	461.1	0.0	521.9
Software	500.0	0.0	0.0	500.0
Support Equipment	867.4	0.0	0.0	867.4
System Test	2965.0	0.0	0.0	2965.0
Facilities	2550.0	0.0	0.0	2550.0
Operations	295.0	0.0	8108.3	8403.3
Systems Engineering	2398.4	547.0	1216.3	4161.7
Program Management	1174.4	419.3	932.4	2526.1
Sub Total	12918.7	4612.7	10257.0	27788.4
ETO Costs	0.0	0.0	32,326.1	32,326.1
LEO Node Costs	4000.0	0.0	0.0	4000.0
Growth and Fee	6466.7	1763.1	16,276.1	24,505.9
TOTAL	23,385.4	6375.8	58,859.2	88,620.4

Costs Reported in Millions of 1991 Dollars

Figure 4.2-1 shows the breakdown of the LTS DDT&E costs in ranked order. Figure 4.2-2 shows the breakdown of the LTS DDT&E costs by percentage. The LEO node cost makes up the largest single cost at \$4000 M (23.6%), followed by the System Test cost (\$2965 M, 17.5%), Facilities costs (\$2550 M, 15.1%), the Systems Engineering costs (\$2398.4 M, 14.2%), and the

Core Vehicle costs ($2038.9 M, 12.8%) . Support Equipment, Software, Operations planning, and site activation make up the remaining costs.

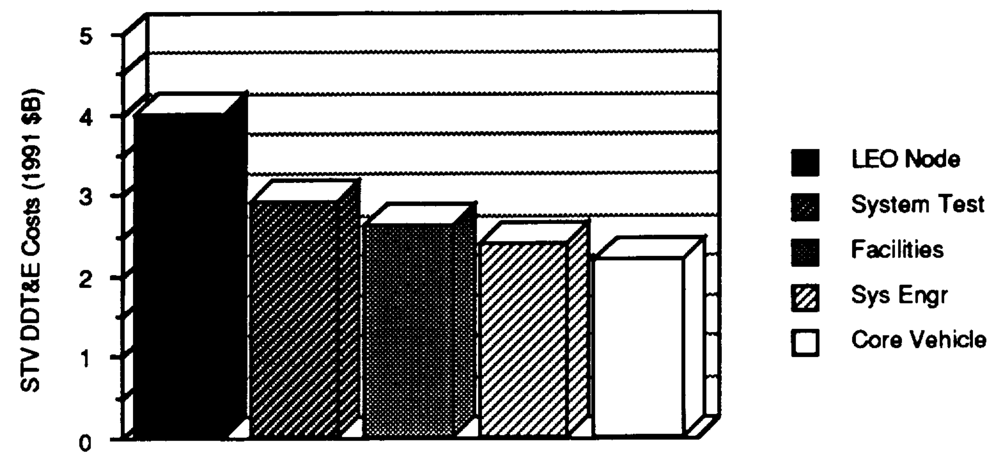


Figure 4.2-1 LTS DDT&E Cost

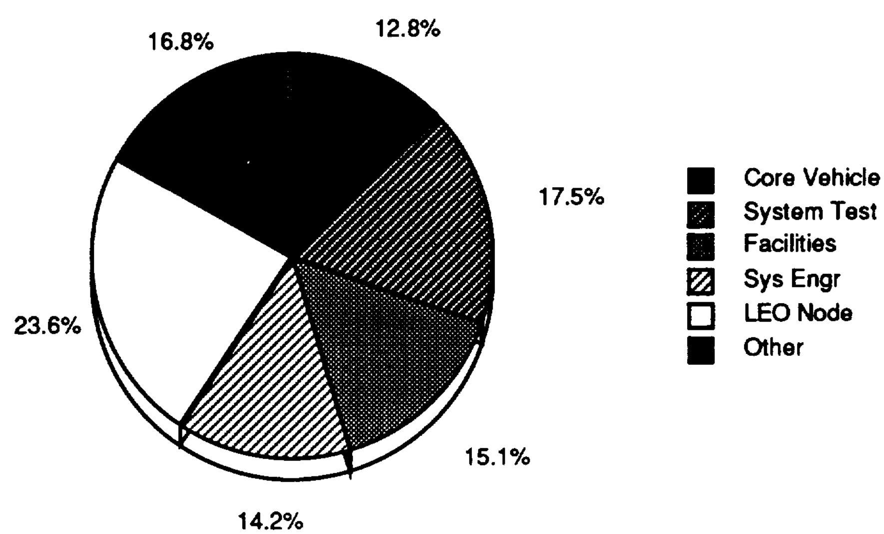


Figure 4.2-2 LTS DDT&E Cost

Figures 4.2-3 and 4.2-4 show the breakdown of the LTS Production costs for 9 vehicles. The Core Vehicle makes up the largest single cost at $2538.7 M (55.0%), followed by the TLI tank costs ($646.6 M, 14.0%), and the Systems Engineering costs ($547.0 M, 11.9%). Other costs including the LOI tanks and Project Management make up the remaining costs.

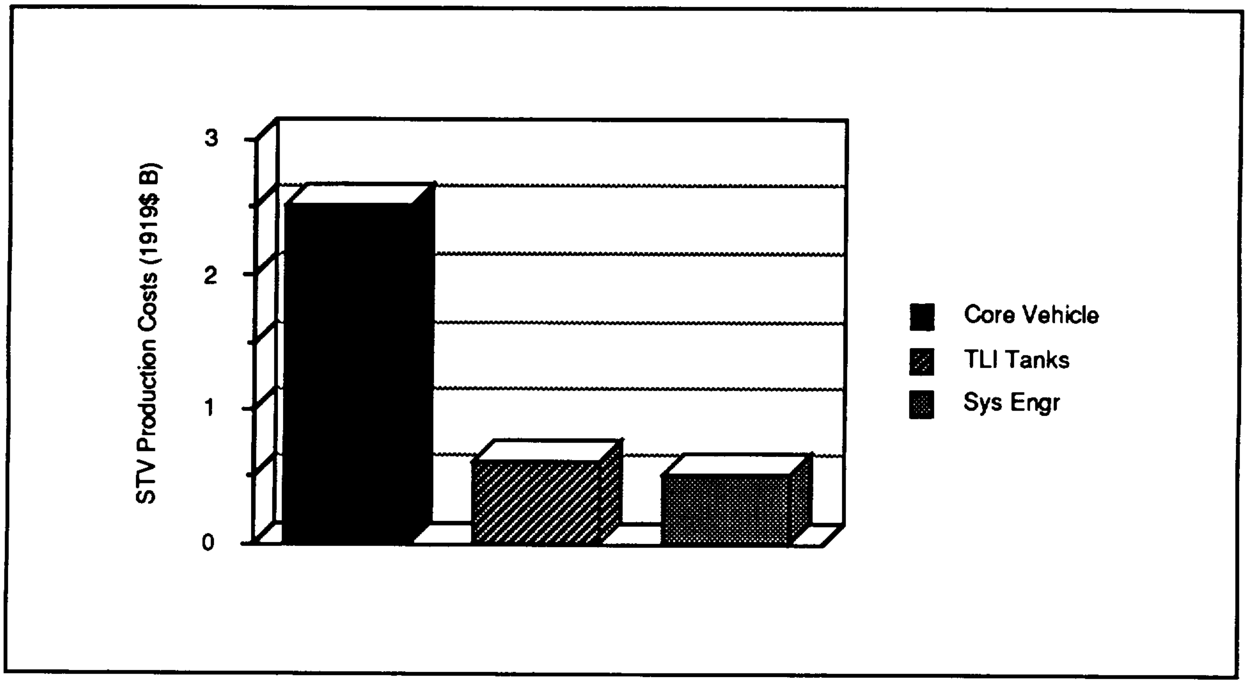


Figure 4.2-3 LTS Production Cost

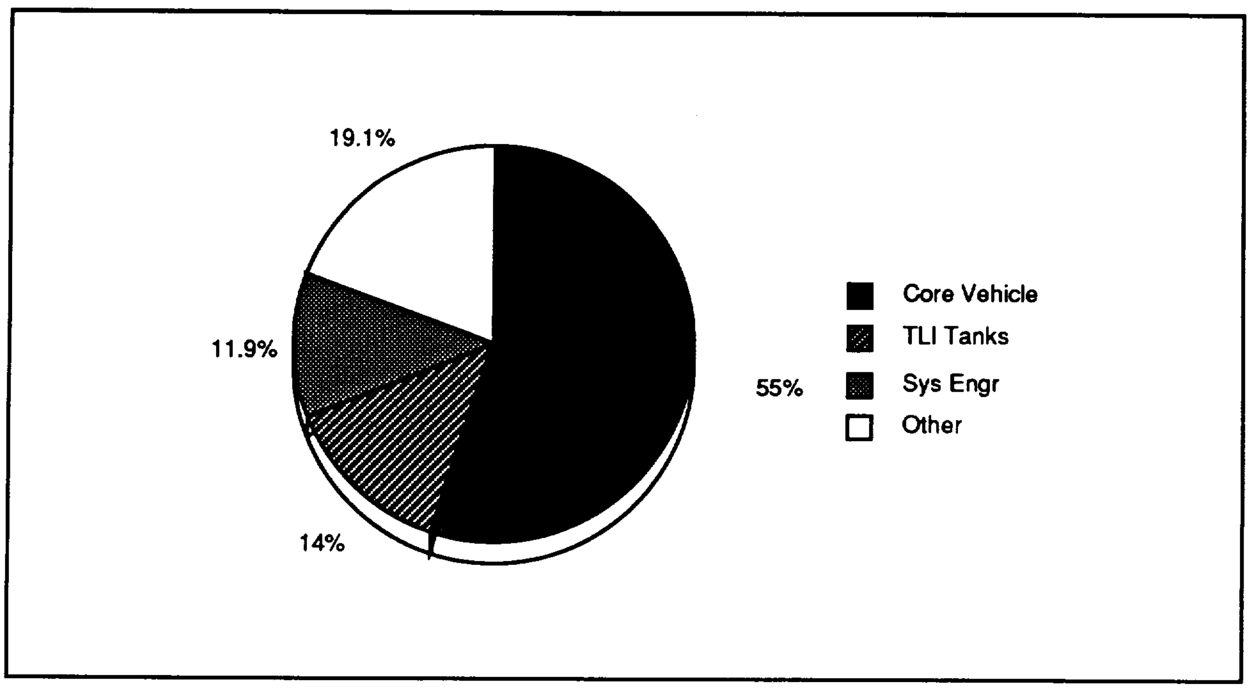


Figure 4.2-4 LTS Production Cost

Figures 4.2-5 and 4.2-6 show the breakdown of the LTS Operations costs for 25 missions. The ETO costs of these missions makes up the largest single cost at $32,326.1 M (75.9%), followed by the Operations cost ($8108.3 M, 19.0%). The Systems Engineering and the Program Management make up the remaining costs.

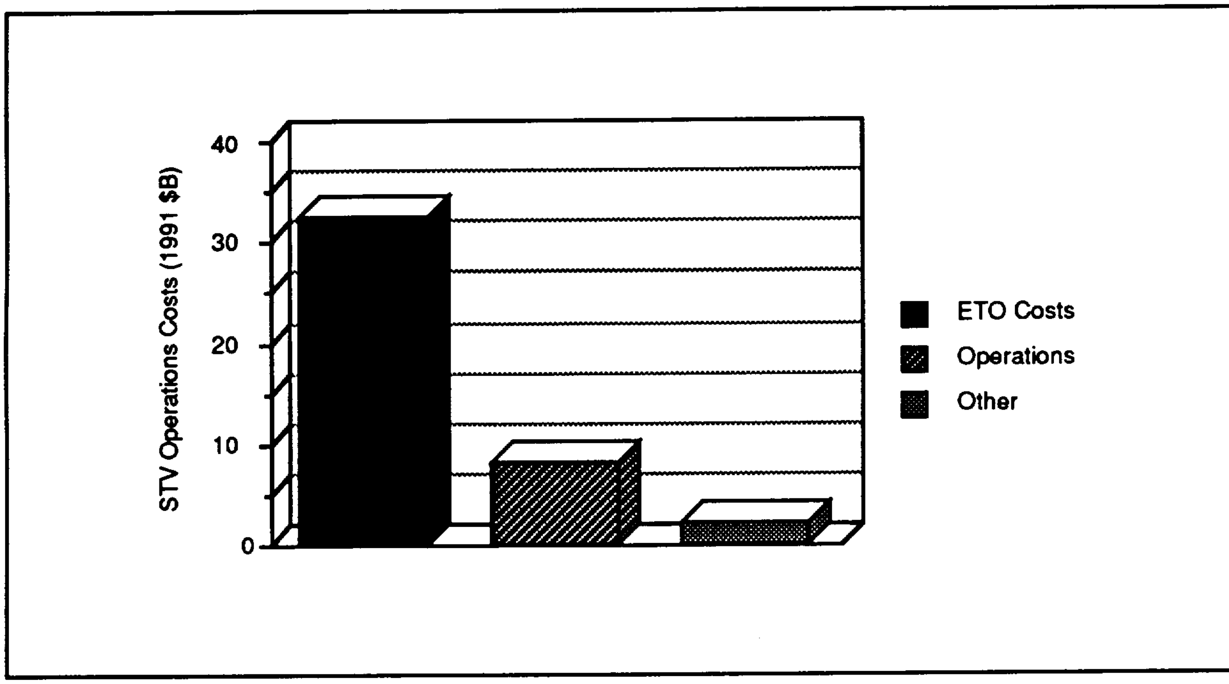


Figure 4.2-5 LTS Operations Costs

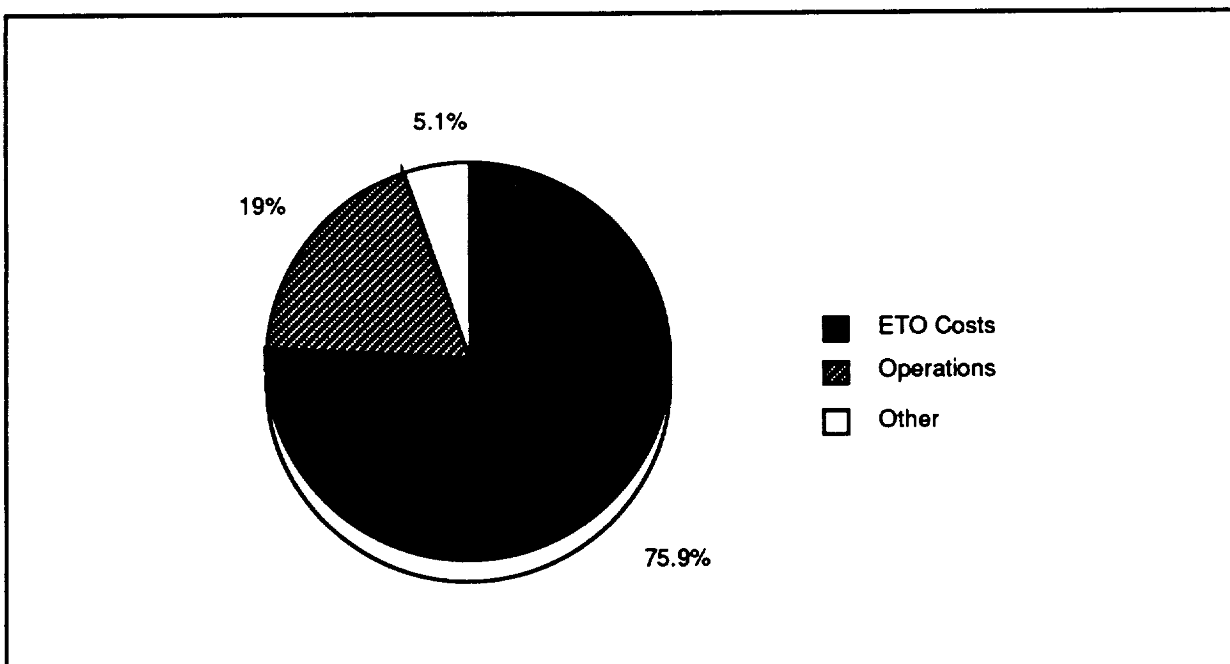


Figure 4.2-6 LTS Operations Costs

4.3 LTS TALL POLE ANALYSIS

A Tall Poles analysis serves to identify and rank the cost elements that make up 80 % of the LCC of a system. The Tall Poles associated with the LTS program are shown in Figure 4.3-1.

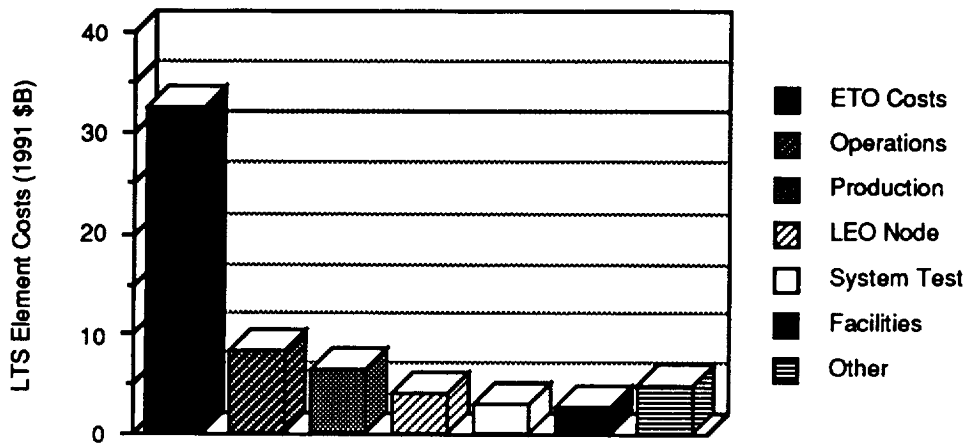


Figure 4.3-1 LTS System Tall Poles

5.0 LTS ECONOMIC ANALYSIS

5.1 LTS COST SENSITIVITIES

The cost analysis associated with the STVC&R Study focused on the overall system support required for point design estimates as well trade study support. Many cost studies were performed during the course of the program and those associated with specific trade studies are documented in Volume II, MCR-91-7503, Final Report. The sensitivities discussed in this volume are those related only to the cost of the Recommended Concept.

5.1.1 Earth To Orbit Cost Sensitivity

The Earth To Orbit (ETO) cost is the single largest element in the LCC of the LTS. Variations in this cost can make a significant difference in the overall cost of the program. Figure 5.1.1-1 shows the sensitivity of the Recommended Concept to variations in the ETO cost. The basic

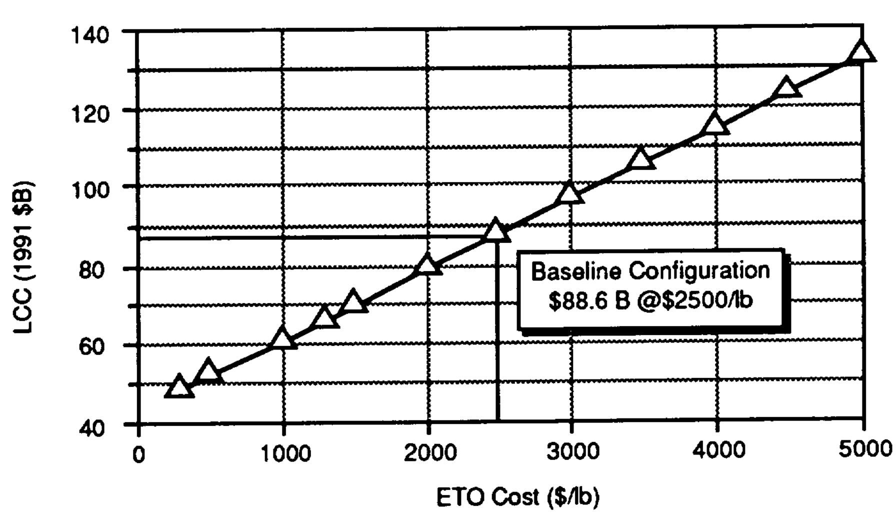


Figure 5.1.1-1 Earth To Orbit Cost Versus LTS Life Cycle Cost

estimates presented in the preceding sections of this report utilized an ETO cost of $2500 per pound of mass delivered to LEO resulting in a LCC of $88.6 B. This cost is representative of a moderately priced vehicle such as the Heavy Lift Launch Vehicle (HLLV). If a more expensive vehicle such as the STS were used, the LCC could be driven as high as $130 B. Conversely, if a low cost vehicle such as the Advanced Launch System (ALS) were used, the LCC could be driven as low as $50 B.

5.1.2 Number of Test Units Sensitivity

Another driving factor in the LCC of the LTS is the requirement for dedicated flight tests of the system prior to any cargo being flown. The Recommended Concept utilizes a single flight test vehicle to perform an equivalent piloted mission to collect data on the performance of the system. This data is analyzed and evaluated to ensure that the system is operating properly, thus reducing the risk of losing valuable cargo. Figure 5.1.2-1 shows the sensitivity of the Recommended Concept to variations in the number of dedicated test flights. If the requirement for a dedicated flight test is removed, the LCC could be lowered to approximately $85 B. If, however, the philosophy used for previous NASA programs such as Apollo were imposed, three dedicated flights would be required. This could drive the LCC to approximately $95 B. Even more stringent requirements could be placed on the system and drive the number of test flights to five. The resulting LCC would be about $100 B.

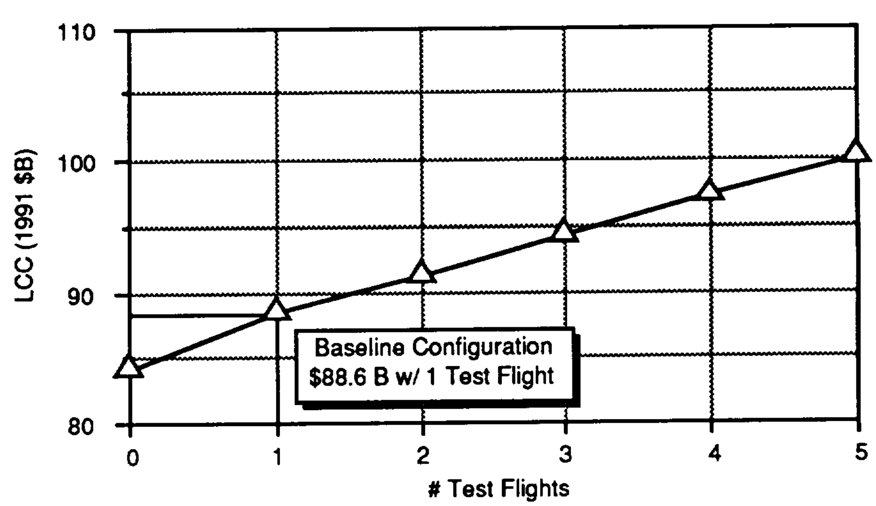


Figure 5.1.2-1 Number of Flight Test Units Versus LTS Life Cycle Cost

6.0 CONCLUSIONS

The recommended concept LTS system can perform the missions efficiently and cost effectively. The current estimate for an average mission is $2609 M (excluding DDT&E costs). Timelines have shown that the system is capable of launching the missions from Space Station Freedom in within the allocated schedule.

The cost estimates for the STV/LTS have been developed utilizing proven cost estimating relationships and calibration factors to account for the enhanced productivity and efficiency introduced by our design approach.

Appendix A

This appendix provides the detailed cost estimating data for the 15' diameter Initial STV. The costs are divided into Development/Validation, Full Scale Development, First Unit, Production, and Integration and Operations.

Cost Elements	DDT&E	First Unit	Production	Operations	LCC
Vehicles	117.8	44.8	689.2	0.0	807.0
Transfer Vehicle	117.8	44.8	689.2	0.0	807.0
Core Vehicle	0.0	0.0	0.0	0.0	0.0
Tanks	0.0	0.0	0.0		0.0
Structure	0.0	0.0	0.0		0.0
Propulsion	0.0	0.0	0.0		0.0
Engines	0.0	0.0	0.0		0.0
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	0.0	0.0	0.0		0.0
TLI Tanks (4 per Vehicle)	117.8	44.8	689.2	0.0	807.0
Tanks	22.6	12.6	194.0		216.6
Structure	5.9	7.2	110.9		116.8
Propulsion	16.8	4.4	67.8		84.6
Engines	25.0	3.0	46.2		71.2
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	47.5	17.6	270.4		317.9
LOI Tanks (2 per Vehicle)	0.0	0.0	0.0	0.0	0.0
Tanks	0.0	0.0	0.0		0.0
Structure	0.0	0.0	0.0		0.0
Propulsion	0.0	0.0	0.0		0.0
Engines	0.0	0.0	0.0		0.0
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	0.0	0.0	0.0		0.0
Aerobrake	0.0	0.0	0.0	0.0	0.0
Tanks	0.0	0.0	0.0		0.0
Structure	0.0	0.0	0.0		0.0
Propulsion	0.0	0.0	0.0		0.0
Engines	0.0	0.0	0.0		0.0
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0	0.0	0.0
Tanks	0.0	0.0	0.0		0.0
Structure	0.0	0.0	0.0		0.0
Propulsion	0.0	0.0	0.0		0.0
Engines	0.0	0.0	0.0		0.0
ECLSS	0.0	0.0	0.0		0.0
Manned Systems	0.0	0.0	0.0		0.0
Other Subsystems	0.0	0.0	0.0		0.0
Software	50.0	0.0	0.0	0.0	50.0
Ground Software	20.0				20.0
Flight Software	30.0				30.0
Support Equipment	17.7	0.0	0.0	0.0	17.7
GSE	17.7				17.7
ASE	0.0				0.0
SSE					0.0
Tooling	25.0	0.0	0.0	0.0	25.0
System Test & Evaluation	67.1	0.0	0.0	0.0	67.1
System Test Hardware (Ground)	44.8				44.8
System Test Hardware (Flight)	0.0				0.0
System Test Operations	22.4				22.4
Facilities	50.0	0.0	0.0	0.0	50.0
Industrial	0.0				0.0
KSC	50.0				50.0
Site Activation	16.5	0.0	0.0	0.0	16.5

Cost Elements	DDT&E	First Unit	Production	Operations	LCC
Other System Requirements					0.0
Payload Integration				220.0	220.0
Ground Operations	2.0			88.0	90.0
Flight Operations	1.0			11.0	12.0
Refurbishment	0.0			0.0	0.0
Logistics	8.0			103.4	111.4
Software Support	2.0			44.0	46.0
Systems Engineering	53.6	6.7	103.4	70.0	226.9
Program Management	41.1	5.1	79.3	53.6	174.0
					0.0
ETO Costs	0.0			5500.0	5500.0
LEO Node (Space Station)	0.0				0.0
					0.0
35% Requirements Growth	158.1	19.8	305.2	2131.5	2594.8
8% Contractor Fee	12.6	1.6	24.4	170.5	207.6
15% Government Support	1.9	0.2	3.7	25.6	31.1
0.5% DCAS Taxes	0.0	0.0	0.0	0.1	0.2
TOTALS	624.4	78.3	1205.1	8417.7	10247.2

Appendix B

This appendix provides the detailed cost estimating data for the Lunar Transfer System (LTS). The costs are divided into Development/Validation, Full Scale Development, First Unit, Production, and Integration and Operations.

Cost Elements	DDT&E	First Unit	Production	Operations	LCC
Vehicles	2168.5	456.2	3646.4	0.0	5814.9
Transfer Vehicle	2168.5	456.2	3646.4	0.0	5814.9
Core Vehicle	1240.9	143.8	1292.4	0.0	2533.3
Tanks	13.1	21.0	189.0		202.1
Structure	82.6	46.4	417.6		500.2
Propulsion	21.6	16.1	144.9		166.5
Engines	878.6	11.0	99.0		977.6
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	245.0	49.1	441.9		686.9
TLI Tanks (4 per Vehicle)	68.8	37.0	646.6	0.0	715.4
Tanks	30.1	21.9	382.4		412.5
Structure	7.9	4.7	81.4		89.3
Propulsion	16.8	4.8	83.1		99.9
Engines	0.0	0.0	0.0		0.0
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	14.0	5.7	99.8		113.8
LOI Tanks (2 per Vehicle)	60.8	26.4	461.1	0.0	521.9
Tanks	30.1	12.6	219.6		249.7
Structure	7.9	2.7	46.4		54.3
Propulsion	8.8	5.5	95.4		104.2
Engines	0.0	0.0	0.0		0.0
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	14.0	5.7	99.8		113.8
Aerobrake	109.5	57.6	288.3	0.0	397.8
Tanks	17.5	3.9	19.3		36.8
Structure	75.8	14.5	72.5		148.3
Propulsion	12.3	2.7	13.5		25.8
Engines	0.0	0.0	0.0		0.0
Aerobrake	0.0	0.0	0.0		0.0
Crew Module	0.0	0.0	0.0		0.0
Other Subsystems	3.9	36.6	183.0		186.9
Crew Module	688.5	191.6	958.0	0.0	1646.5
Tanks	0.0	0.0	0.0		0.0
Structure	42.2	31.5	157.5		199.7
Propulsion	0.0	0.0	0.0		0.0
Engines	0.0	0.0	0.0		0.0
ECLSS	270.5	82.0	410.0		680.5
Manned Systems	84.3	17.3	86.5		170.8
Other Subsystems	291.5	60.8	304.0		595.5
Software	500.0	0.0	0.0	0.0	500.0
Ground Software	200.0				200.0
Flight Software	300.0				300.0
Support Equipment	867.4	0.0	0.0	0.0	867.4
GSE	325.3				325.3
ASE	542.1				542.1
SSE					0.0
Tooling	25.0	0.0	0.0	0.0	25.0
System Test & Evaluation	2965.0	0.0	0.0	0.0	2965.0
System Test Hardware (Ground)	1824.6				1824.6
System Test Hardware (Flight)	912.3				912.3
System Test Operations	228.1				228.1
Facilities	2550.0	0.0	0.0	0.0	2550.0
Industrial	0.0				0.0
KSC	2550.0				2550.0
Site Activation	841.5	0.0	0.0	0.0	841.5

Cost Elements	DDT&E	First Unit	Production	Operations	LCC
Other System Requirements					0.0
Payload Integration				1000.0	1000.0
Ground Operations	50.0			198.8	248.8
Flight Operations	100.0			3220.0	3320.0
Refurbishment	25.0			2642.5	2667.5
Logistics	80.0			547.0	627.0
Software Support	40.0			500.0	540.0
Systems Engineering	1531.9	68.4	547.0	1216.2	3295.1
Program Management	1174.4	52.5	419.3	932.4	2526.2
					0.0
ETO Costs	0.0			32326.1	32326.1
LEO Node (Space Station)	4000.0				4000.0
					0.0
35% Requirements Growth	5921.5	202.0	1614.4	14904.1	22440.0
8% Contractor Fee	473.7	16.2	129.2	1192.3	1795.2
15% Government Support	71.1	2.4	19.4	178.8	269.3
0.5% DCAS Taxes	0.4	0.0	0.1	0.9	1.3
TOTALS	23385.3	797.6	8375.8	58859.2	88620.2